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Research of the EUV radiation and CO_2 Laser produced tin plasma

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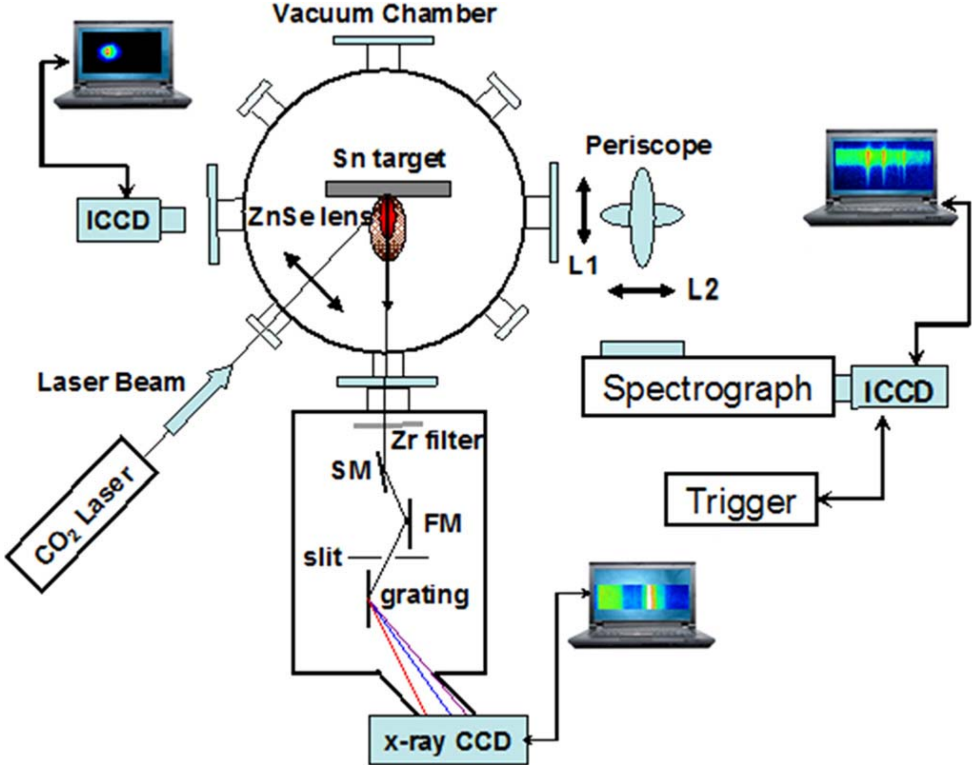
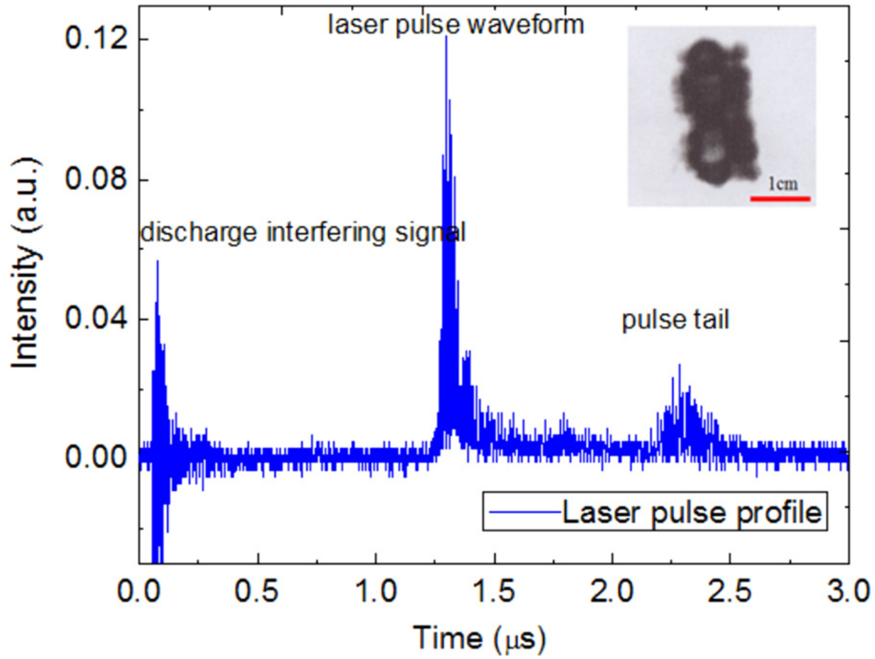
Introduction

Experiments of pulse CO_2 laser produced tin plasma had been carried out. Time-integrated extreme ultraviolet spectral measurement showed that the peak of the spectrum was located at 13.5 nm. Plasma parameters of electron temperature and density measurements both in axial and radial direction had been performed from a two-dimensional time and space resolved image spectra analysis. Debris speed of laser produced plasma in various buffer gas was quantitatively estimated by means of a fast gated intensified charge coupled device imaging system as well as by visible emission spectroscopy. The stopping power of the hydrogen buffer gas was assessed under ambient pressure ranging from 30 to 104 Pa.

●Experimental setup



CO_2 laser parameters：

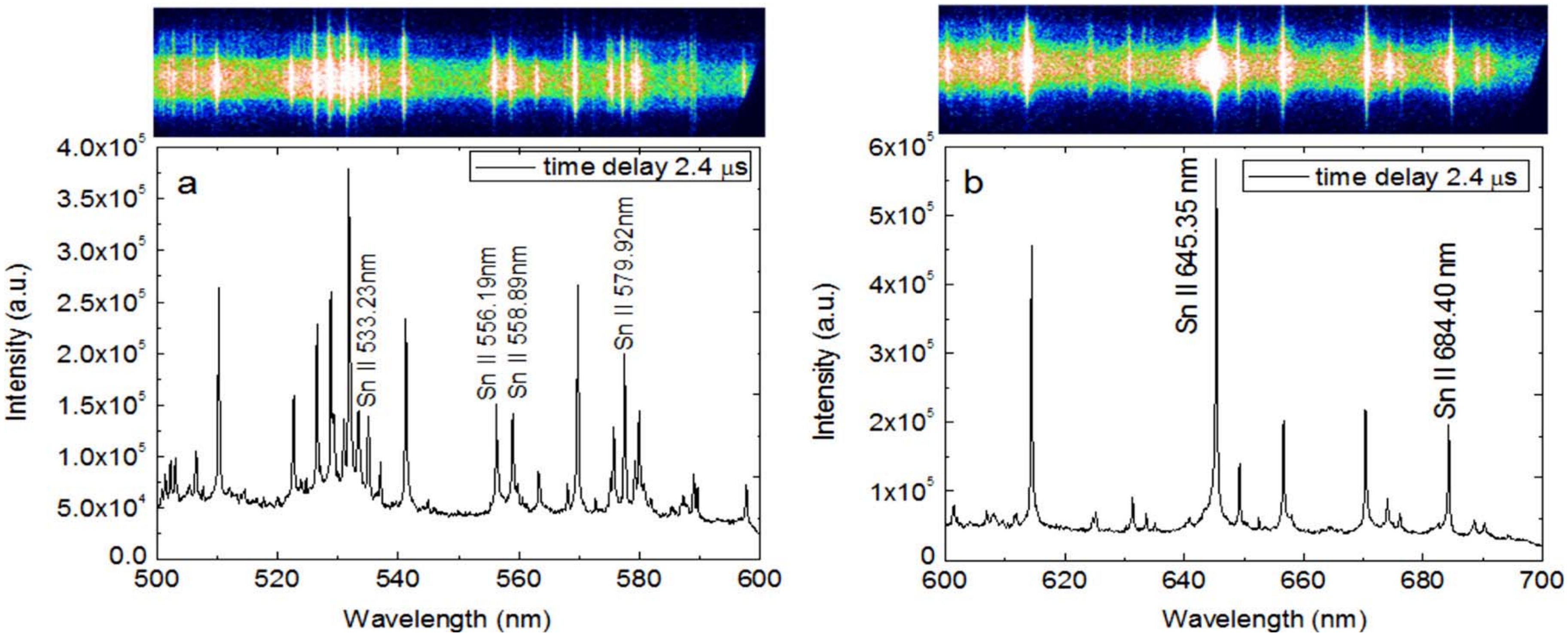


Pulse energy：400 mJ

FWHM：75 ns

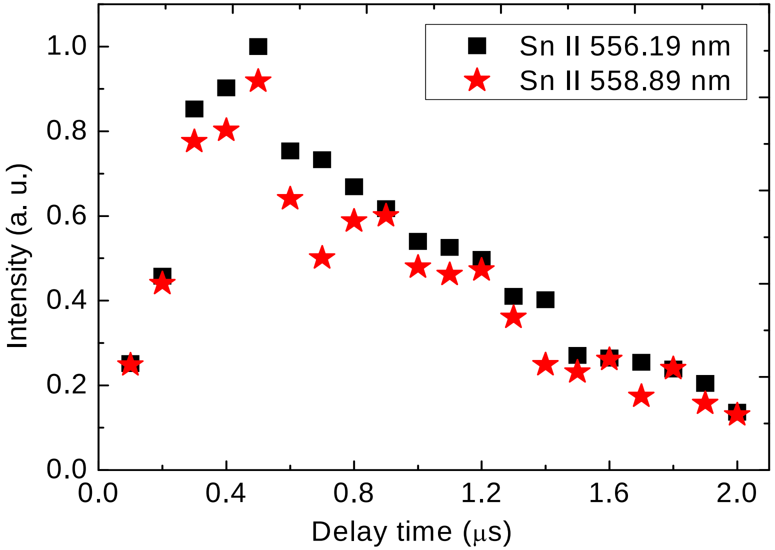
Focus：9.525 cm

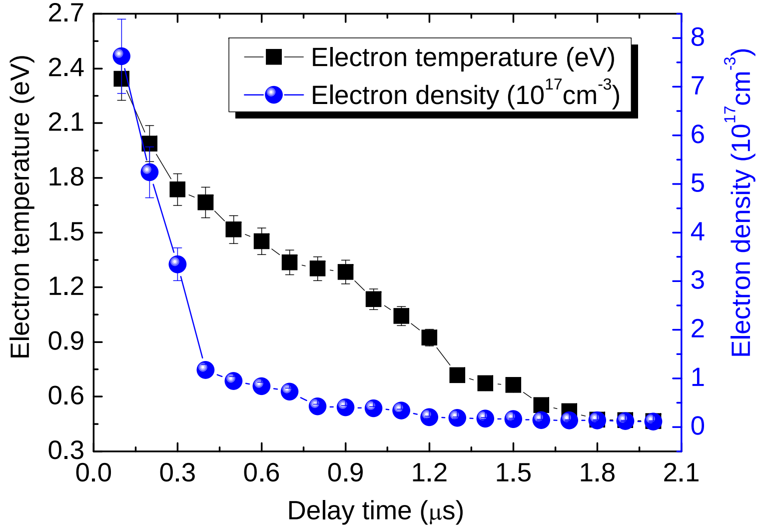
●Spectrum of CO_2 laser produced Tin plasma



Radial space-resolved spectrum (bottom) and raw spectroscopic image (top) of tin plasma plume for a time delay of 2.4 μs after pulse discharge with a gate width of 50 ns.

➢Time-resolved CO_2 laser produced Sn plasma





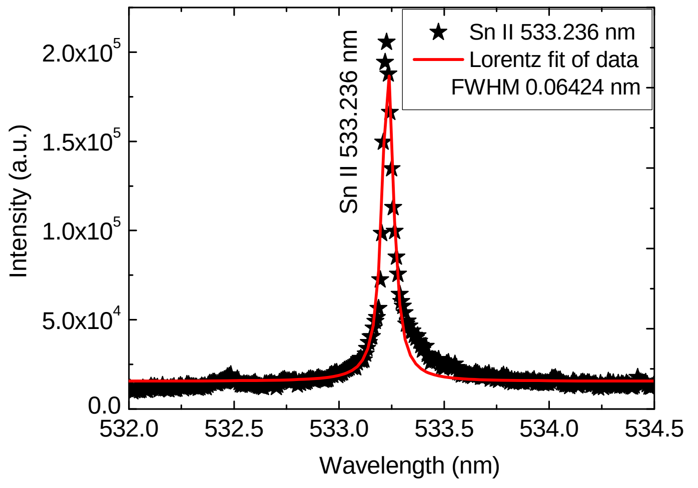
•The CW spectrum is strong in the early stage of the plasma (<100 ns), the intensity of the Sn II spectrum first increase with delay time, and then begin to decrease.

•Both the electron temperature and density decrease with delay time, but they decrease fast in the early stage of the plasma.

●Space-resolved CO_2 laser produced Sn plasma

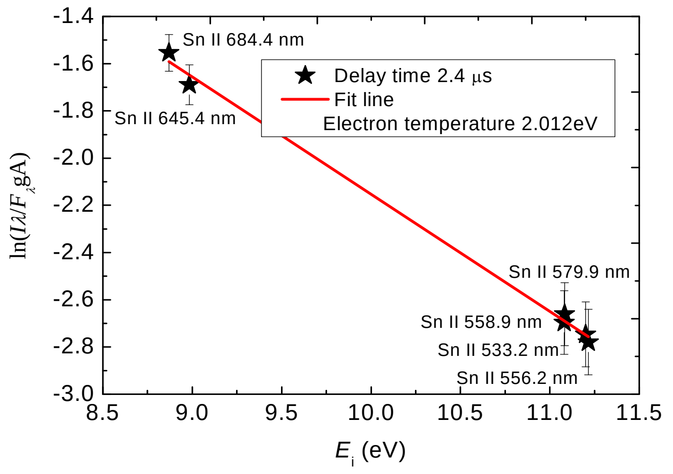
Stark broaden method

$$\Delta\lambda_{1/2} = 2W_p\left(\frac{n_e}{10^{16}}\right)[1+1.75G(\frac{n_e}{10^{16}})^{1/4}(1-\frac{3}{4}N_D^{-1/3})]$$

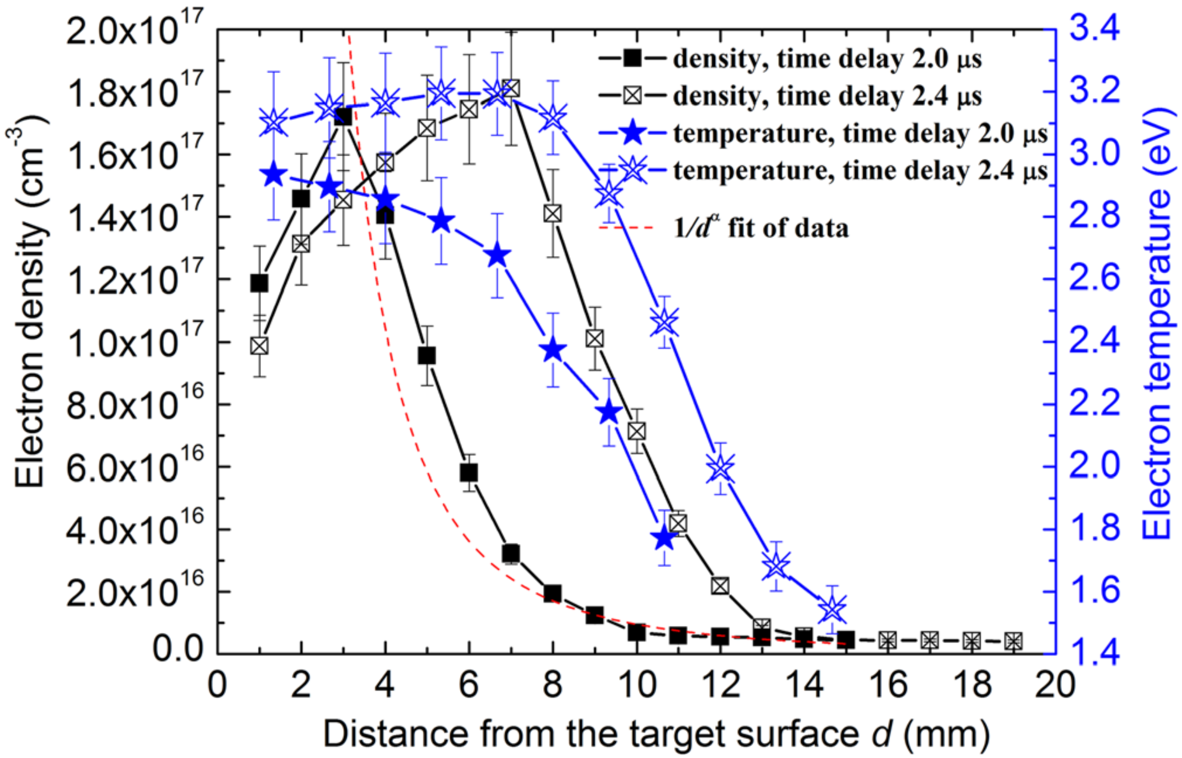


Boltzmann plot method

$$\ln(\frac{I_{ij,\lambda}\lambda_{ij}}{F_\lambda g_i A_{ij}}) = -\frac{1}{k_B T}E_i + \ln\left(\frac{hcLn_z}{4\pi P_z}\right)$$

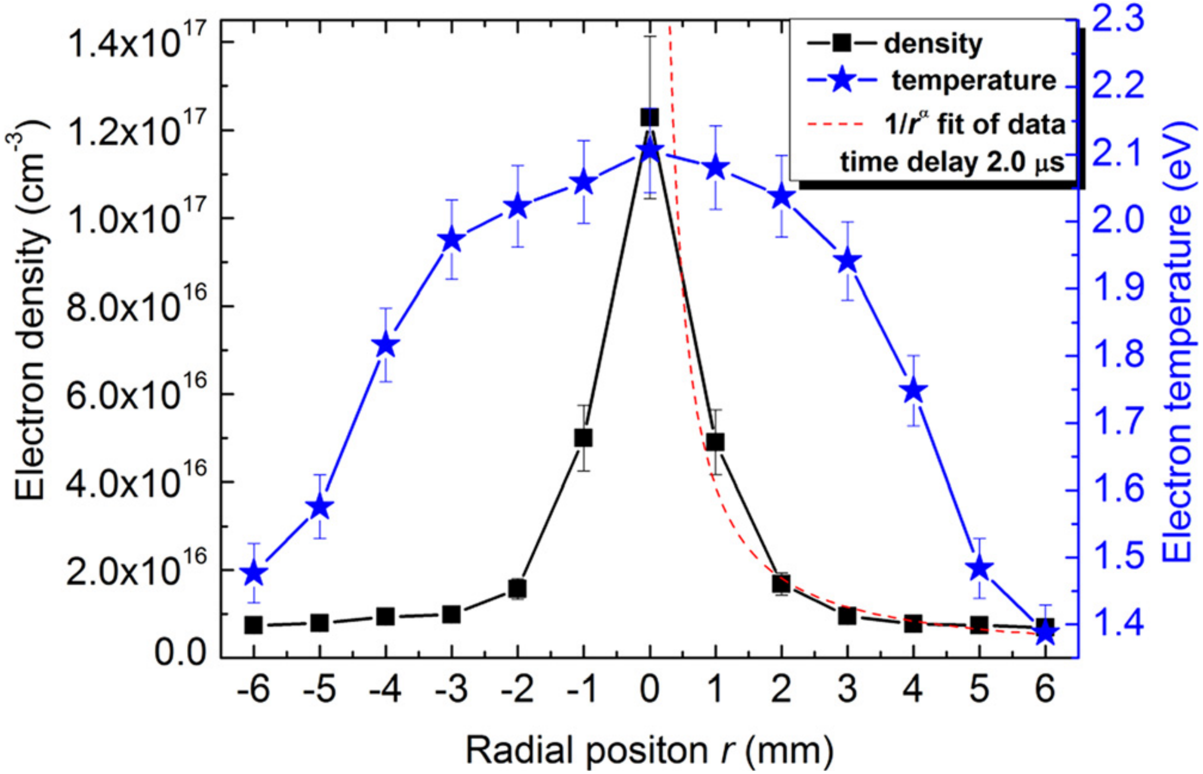


●The axial spatial distribution of the electron temperature and density



➢**The axial spatial distribution of the electron density decay as 1/$d^{2.6}$.**
➢**Near the target surface, the electron temperature Te varied slightly, as the axial distance increased, the electron temperature decreased rapidly.**

•Radial distribution of plasma temperature and density

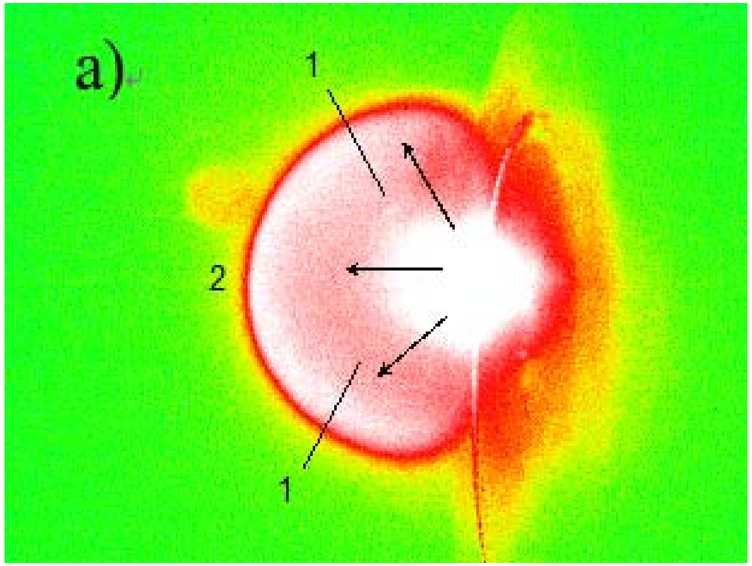


➢**The radial spatial distribution of the electron density decay as** $1/r^{1.1}$**.**

➢**The radial distribution of the plasma plume has good symmetry.**

•Boundary of the plasma plume

$$r = r_0 \cos^q \theta$$



•Debris kinetic energy

$$K = \frac{1}{2} m \left(\frac{dx}{dt} \right)^2$$

•Debris mitigation power

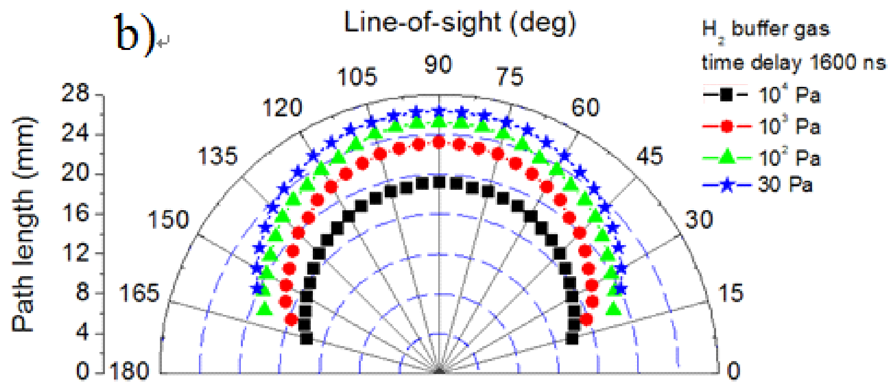
$$S = \frac{\mathrm{d}K}{\mathrm{d}x}$$

•scattering cross section

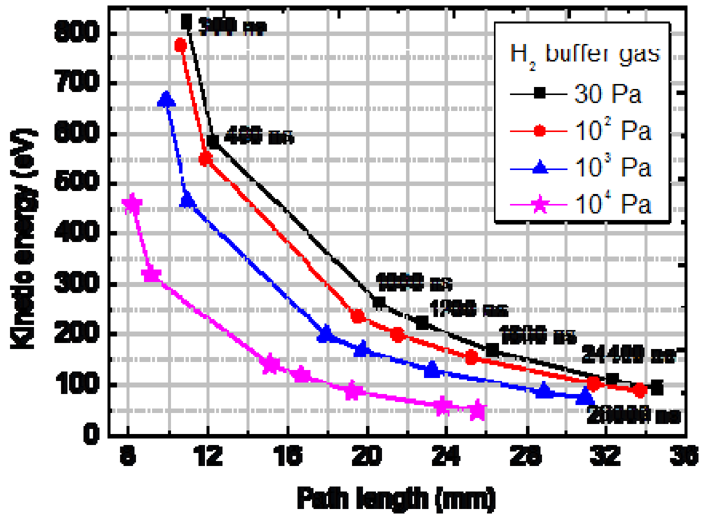
$$\sigma = \frac{dK / dx}{Kn}$$

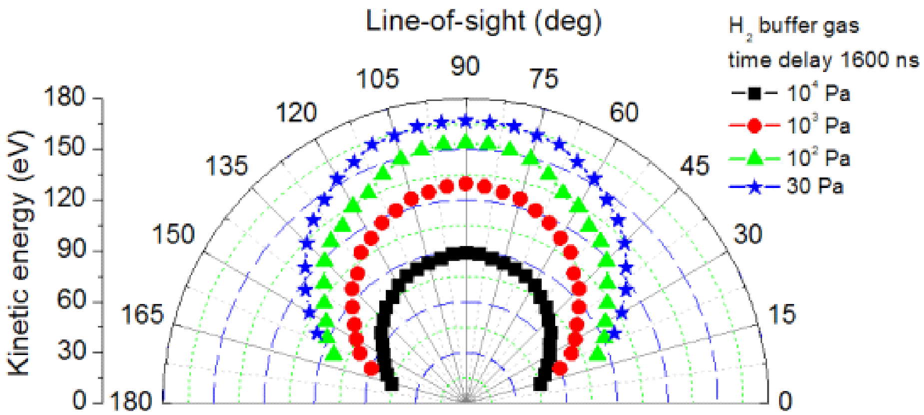
•buffer gas：H_2、He and Ar

●H_2 pressure(30 Pa, 100 Pa, 1000 Pa, 10000 Pa)



plume edges

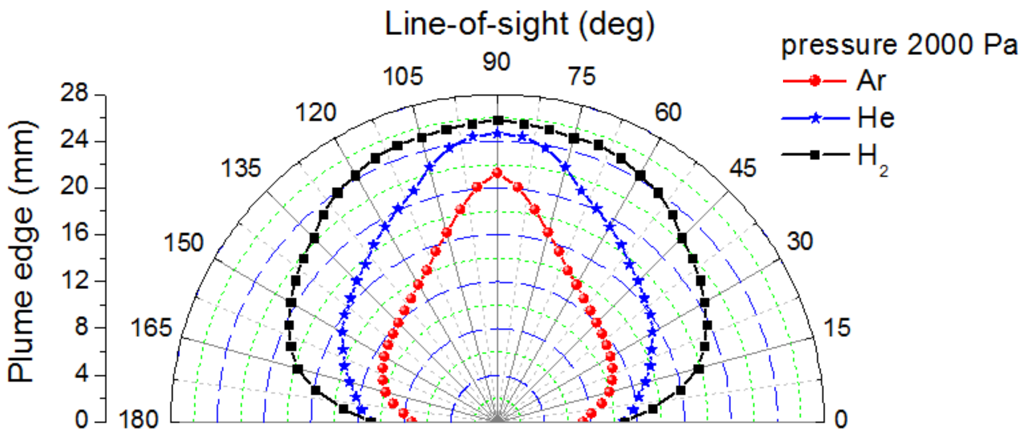




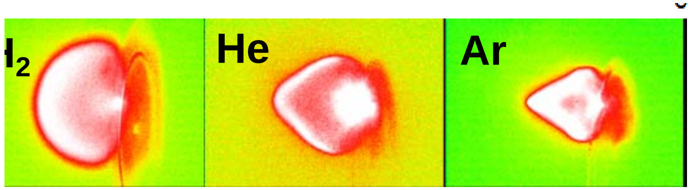
Debris kinetic energy

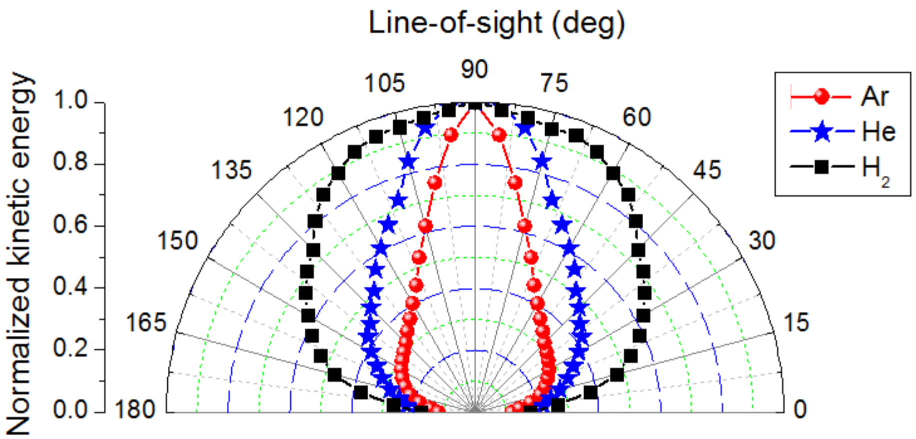
➢**The interaction with the buffer gas produces a deceleration of the kinetic energy, and it decreases with increasing gas pressure at a specific path length.**

●Plasma in H_2, He and Ar buffer gas



Plume edges





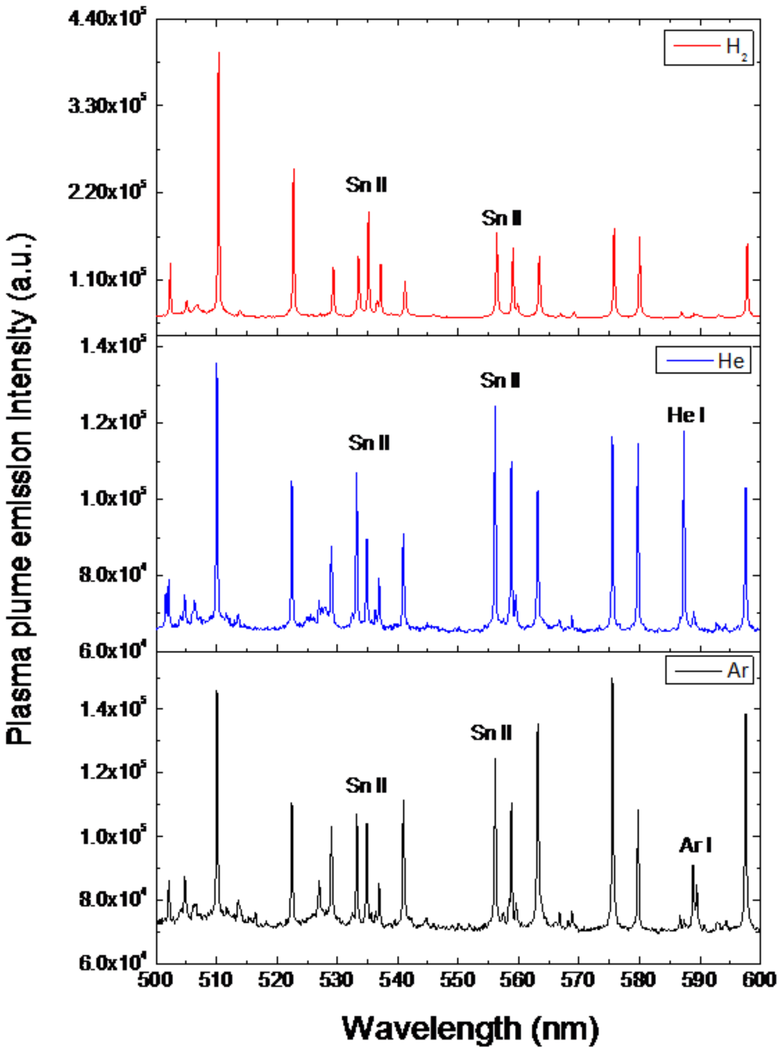
Normalized kinetic energy

H_2: q=0.38

He: q=1.01

Ar: q=2.66

●the mechanism of ion debris speed mitigating

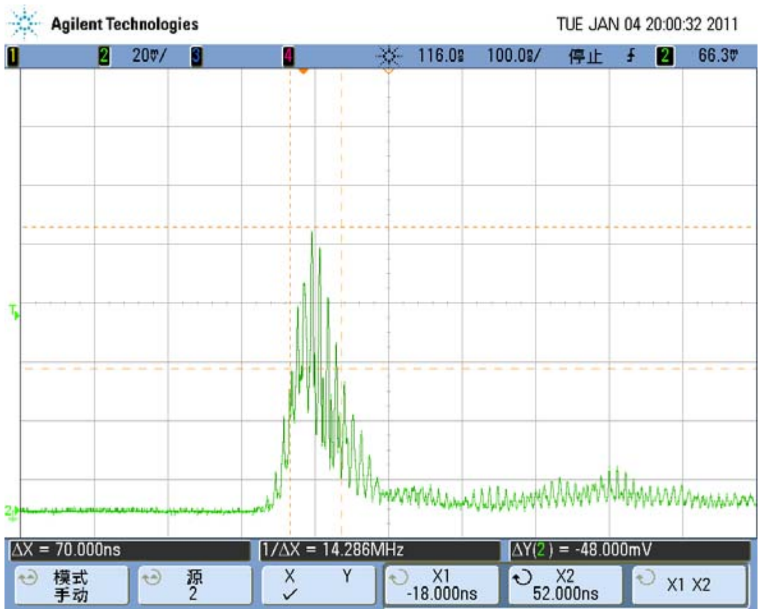


- ➢Typical emission spectra of the CO2 laser produced tin plasma

- ➢Thermalizing collisions are mainly responsible for the debris speed mitigation.

●Target and the EUV spectrum

Laser pulse energy: 600 mJ
Pulse width 70 ns

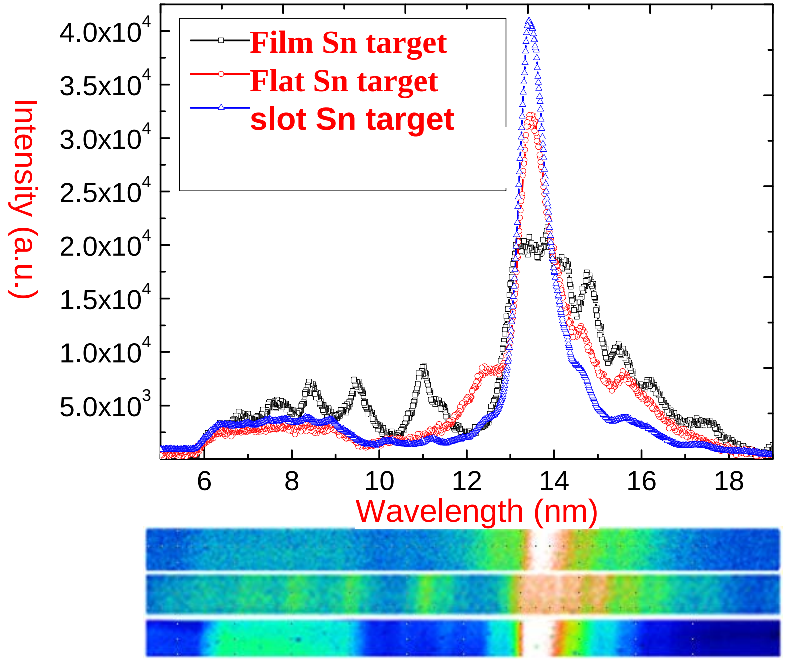


13.5 nm spectrum width

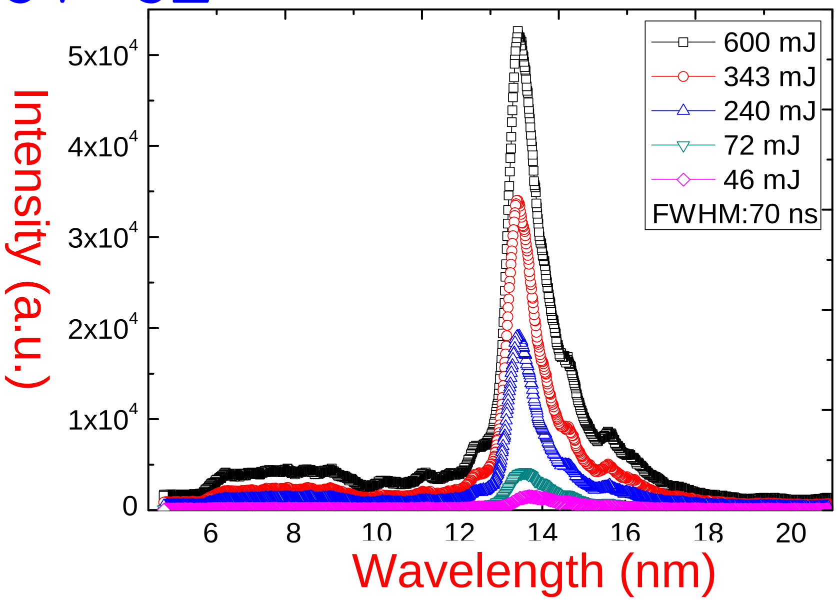
Film Sn target: 2.3 nm

Flat Sn target : 1.1 nm

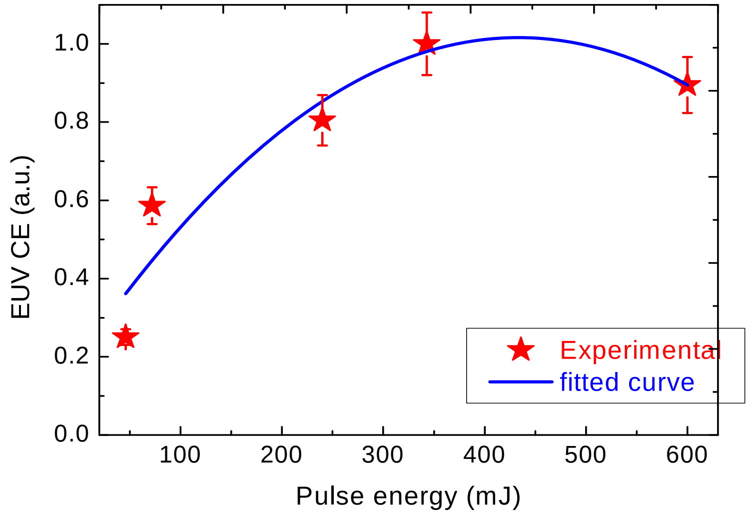
Sn target with slot: 0.7 nm



●Pulse energy and EUV-CE

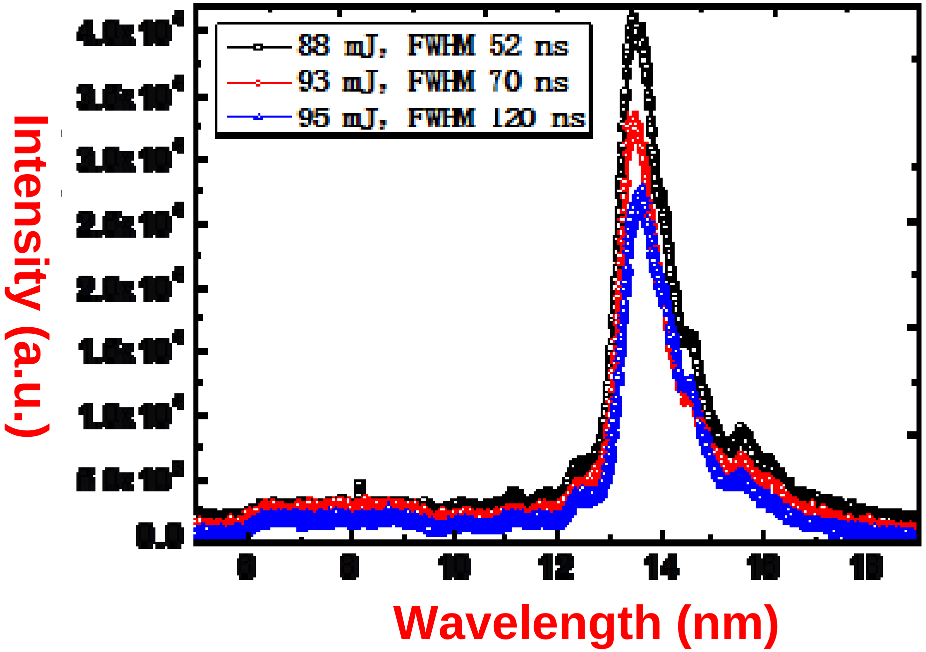


•Threshold pulse energy: 30 mJ

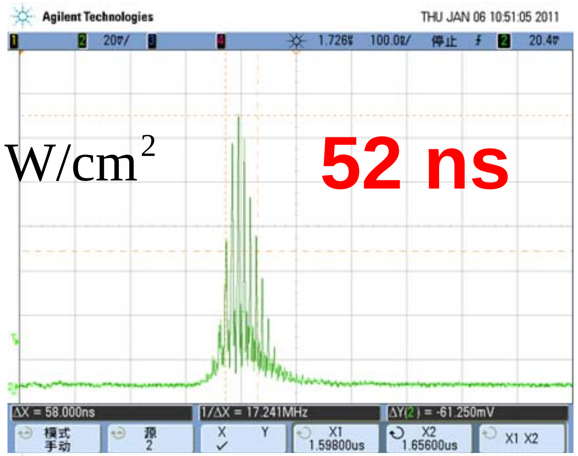


•The highest EUV-CE at 343 mJ, peak power density 2×10^{10} W/cm^2

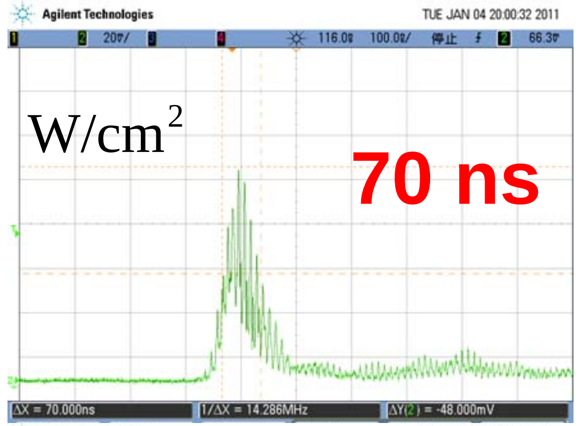
●Laser pulse width



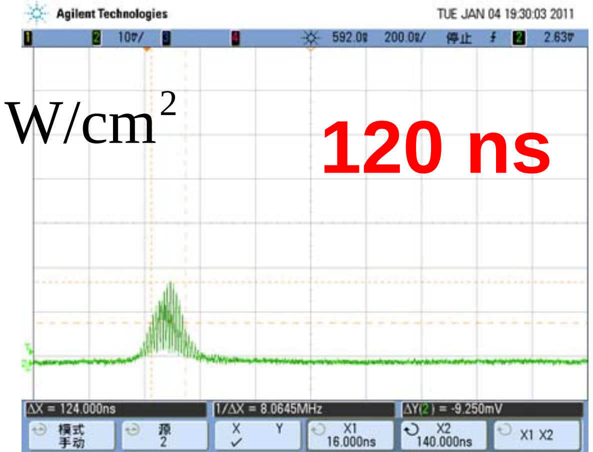
5.4×10^9 W/cm^2



4.2×10^9 W/cm^2



2.5×10^9 W/cm^2



Peak power is the main factor to influence the EUV radiation

●Conclusions

•The research of the spatial, and temporal emission characteristic of CO_2 laser produced Sn plasma have shown that the axial spatial distribution of the electron density decay as $1/d^{2.6}$, while The radial spatial distribution of the electron density decay as $1/r^{1.1}$.

•The speed mitigation power of hydrogen, helium and argon buffer gas against CO_2 laser produced tin plume debris were quantitatively estimated by means of a fast gated intensified charge coupled device imaging system.

•The spectral properties of the EUV emission around 13.5 nm from plate, cavity, and thin foil tin targets and the dependence of EUV absorption coefficient on different air, Ar, He and H_2 buffer gas pressure were investigated.